Seismic Design of Concrete Structure

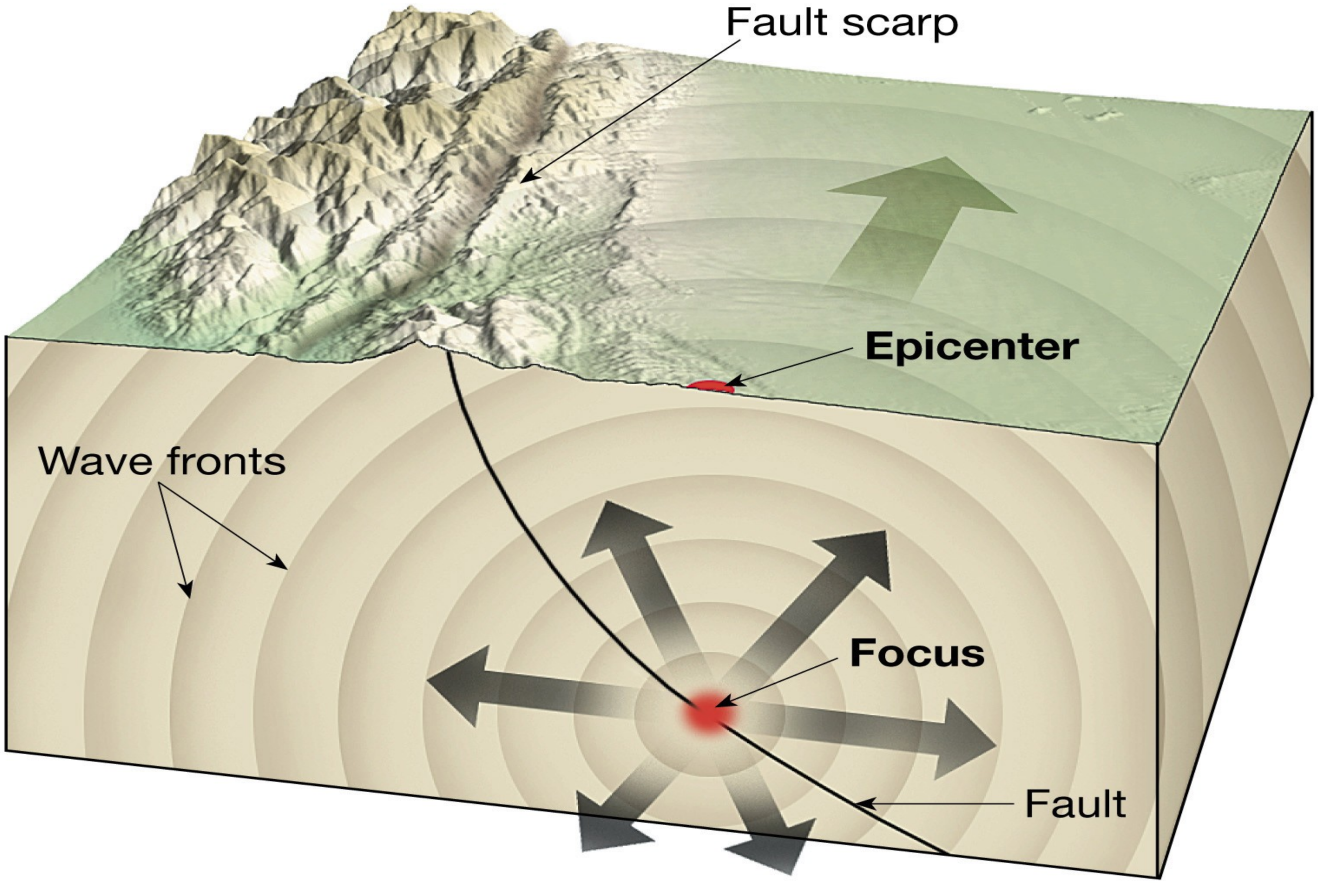
Seismic Design of Concrete Structure

- **Earthquakes occur in many regions of the world. In certain locations where the intensity of the ground shaking is small, the designer does not have to consider seismic effects.**

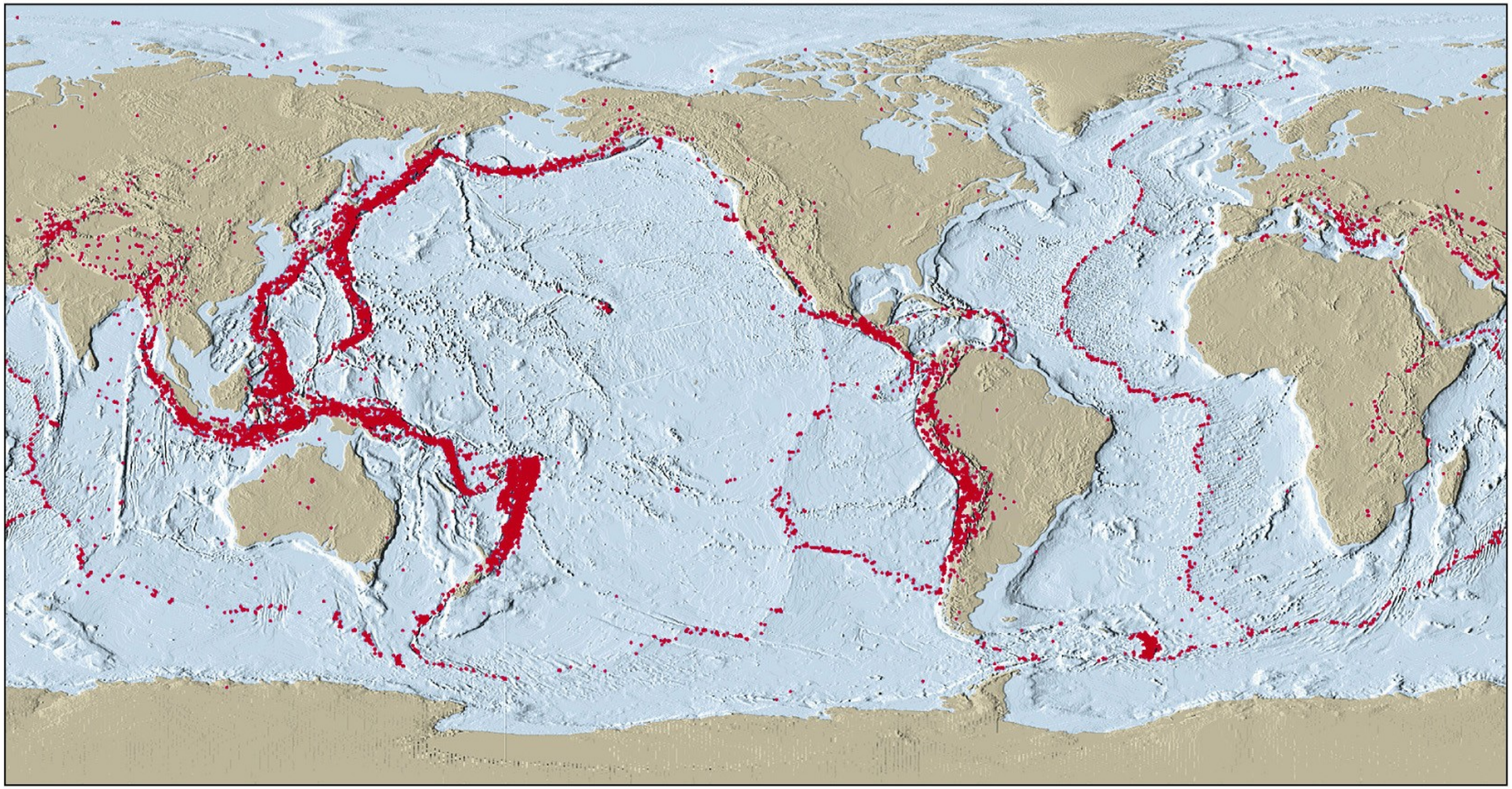
- **In other locations-particularly in regions near an active geological fault (a fracture line in the rock structure), such as the San Andreas fault that runs along the western coast of California-large ground motions frequently occur that can damage or destroy buildings and bridges in large areas of cities**

- **Assuming the building is fixed at its base, the displacement of floors will vary from zero at the base to a maximum at the roof**

Earthquake focus and epicenter

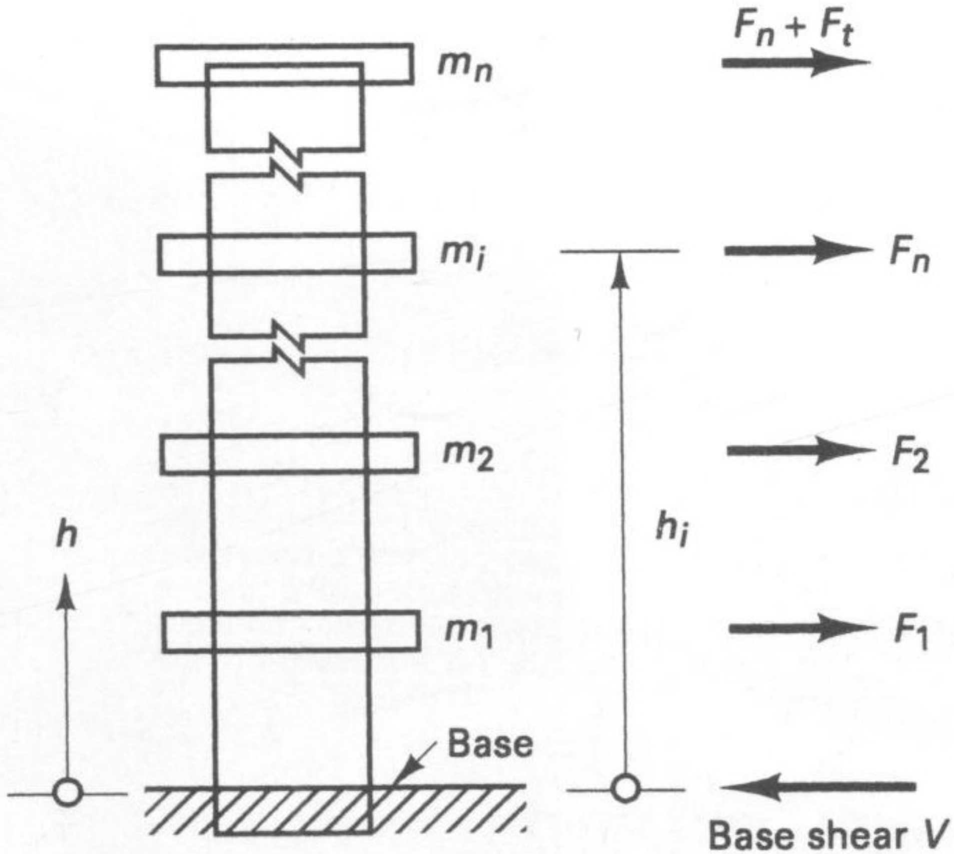


Distribution of magnitude 5 or greater earthquakes, 1980 - 1990

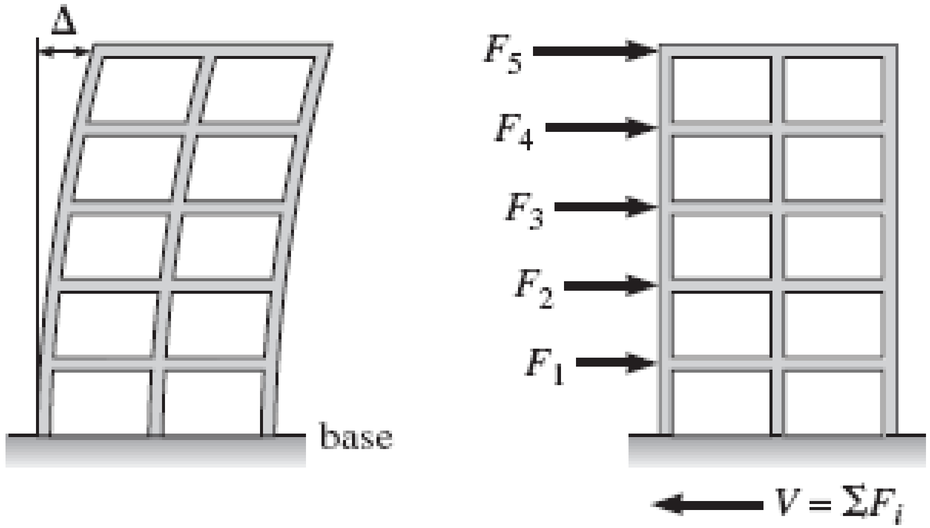





KATO



Modeling multistory structures



There are several analytical procedures to determine the magnitude of the base shear for which buildings must be designed, we will only consider the *equivalent lateral force procedure*, **described in the ANSI/ASCE and UBC standard. Using this procedure, we compute the magnitude of the base shear as**

$$V = \frac{S_{D1}W}{T(R/I)}$$

but not to exceed

$$V_{max} = \frac{S_{DS}W}{R/I}$$

and not less than

$$V_{min} = 0.0441 I S_{DS} W$$

where W = total dead load of building and its permanent equipment and partitions

1. In areas used for storage, a minimum of 25% of the reduced floor live load (floor live load in public garages and open parking structures need not be included.)
2. Where an allowance for partition load is included in the floor load design, the actual partition weight of 10 psf of floor area, whichever is greater.
3. Total weight of permanent operating equipment
4. 20% of flat roof snow load where flat snow load exceeds 30 psf (1.44 kN/m^2).

T = fundamental natural period of building, which can be computed by the following empirical equation

$$T = C_T h_n^{3/4}$$

where h_n = the building height in feet (meters), $C_T = 0.35$ (or 0.0853 in SI units) for steel rigid frames, $C_T = 0.03$ (0.0731 SI) for reinforced concrete rigid frames, and $C_T = 0.02$ (0.0488 SI) for most other systems.

S_{D1} = a factor computed using seismic maps that shows intensity of design earthquake for structures with $T = 1$ s.

S_{DS} = a factor computed using seismic maps that shows intensity of design earthquake at particular locations for structures with $T = 0.2$ s.

Palestine

$S_{D1} = 0.10$

$S_{DS} = 0.21$

R = *response modification factor,* which represents the ability of a structural system to resist seismic forces. This factor, which varies from 8 to 1.25, is tabulated in Table 1 for several common structural systems. The highest values are assigned to ductile systems; the lowest values, to brittle systems.

TABLE 1

Values of *R* for Several Common Lateral Bracing Structural Systems

Description of Structural System	R
Ductile steel or concrete frame with rigid joints	8
Ordinary reinforced concrete shear walls	4
Ordinary reinforced masonry shear wall	2

I = *occupancy importance factor,* which represents how essential a given structure is to the community. For example, I is 1 for office buildings, but increases to 1.5 for hospitals, police stations, or other public facilities vital to the safety and well-being of the community or whose failure might cause large loss of life.

Table 2:
Design Coefficients & Factors for Basic Seismic-Force-Resisting Systems

Basic Seismic-Force-Resisting System	Response Modification Coefficient R	Deflection Amplification Factor, c_d
Bearing Wall System		
Special reinforced concrete shear wall	5.5	5
Ordinary reinforced concrete shear wall	4.5	4
Detailed plain concrete shear walls	2.5	2
Ordinary plain concrete shear walls	1.5	1.5
Building Frame System		
Ordinary reinforced concrete shear wall	5	4.5
Detailed plain concrete shear walls	3	2.5
Ordinary plain concrete shear walls	2	2
Moment Resistant Frames		
Special reinforced concrete moment frames	8	5.5
Intermediate reinforced concrete moment frames	5	4.5
Ordinary reinforced concrete moment frames	3	2.5
Dual System with Special Moment Frames		
Special reinforced concrete shear walls	8	6.5
Ordinary reinforced concrete shear walls	7	6
Dual System with Intermediate Moment Frames		
Special reinforced concrete shear walls	6	5
Ordinary reinforced concrete shear walls	5.5	4.5
Shear wall-frame Interactive system with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls	5.5	5

Distribution of Seismic Base Shear V to Each Floor Level

The distribution of the *seismic base shear* V to each floor is computed using

$$F_x = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} V$$

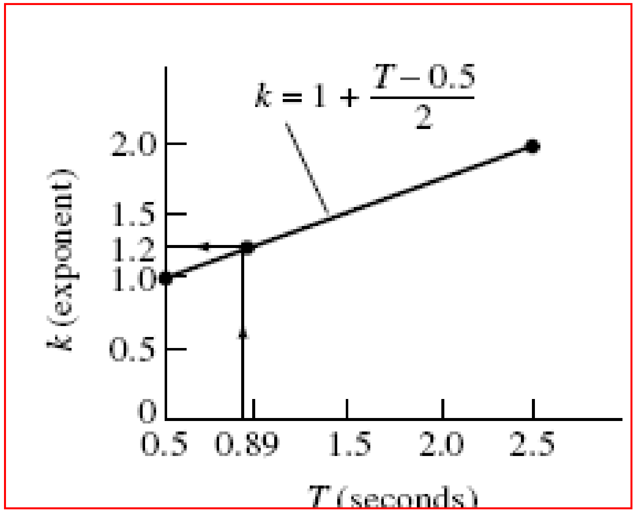
where F_x = the lateral seismic force at level x

w_i and w_x = deadweight of floor at levels i and x

h_i and h_x = height from base to floors at levels i and x

k = 1 for $T < 0.5$ second, 2 for $T > 2.5$ s. For structures with a period between 0.5 and 2.5 s, k is determined by linear interpolation between T equal to 1 and 2 as

$$k = 1 + \frac{T - 0.5}{2}$$



Story Drift & The P-Delta Effect

(a) *Drift:* The design story drift, Δ, is computed as the difference between the deflections of the center of mass at the top and bottom of the story being considered.

The deflection of level X is to be determined from the following expression,

$$\delta_x = \frac{C_d \delta_{xe}}{I}$$

where,

C_d = Deflection amplification factor

δ_x = Deflections (in. or mm) determined by an elastic analysis of the seismic forces resisting system

I = Occupancy importance factor

The design story drift, Δ, has to be increased by an incremental factor relating to the P-delta effects. The redundancy coefficient, ρ, in the case of drift should be taken as 1.0.

(b) *P-Delta effects:* The *P*-Delta effects can be disregarded if the stability coefficient, θ, from the following expression is equal or less than 0.10,

$$\theta = \frac{P_x \Delta}{V_x h_{sx} C_d}$$

where,

P_x = The total unfactored vertical design load at and above level x (kip or kN); when calculating the vertical design load for purposes of determining *P*-Delta, the individual load factors need not exceed 1.0

Δ = The design story drift (in. or mm) occurring simultaneously with V_x

V_x = The seismic shear force (kip of kN) acting between level x and $x - 1$

h_{sx} = The story height (ft or m) below level x

C_d = The deflection amplification factor

The stability coefficient, θ, shall not exceed θ_{max} determined as follows:

$$\theta_{max} = \frac{0.5}{C_d \beta} \leq 0.25$$

where:

β = The ratio of shear demand to shear capacity for the story between level x and $x - 1$. Where the ratio β is not calculated, a value of $\beta = 1.0$ shall be used.

When the stability coefficient, θ, is greater than 0.10 but less than or equal to θ_{max}, inter-story drifts and element forces shall be computed including P-Delta effects. To obtain the story drift for including the P = Delta effect, the design story drift shall be multiplied by 1.0/(1-θ).

Where θ is greater than θ_{max}, the structure is potentially unstable and has to be re-designed.

Allowable Story Drift, Δ

Allowable Story Drift, Δ (in. or mm)[a]

Building	Seismic Use Group		
	I	II	III
Buildings, other than masonry shear wall or masonry wall frame buildings, four stories or less in height with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}$[b]	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall buildings[c]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall buildings	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
Masonry wall frame buildings	$0.013h_{sx}$	$0.013h_{sx}$	$0.010h_{sx}$
All other buildings	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a]There shall be no drift limit for single-story buildings with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.

[b]h_{sx} is the story height below level x.

[c]Buildings in which the basic structural system consists of masonry shear walls as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible.

Important Factor

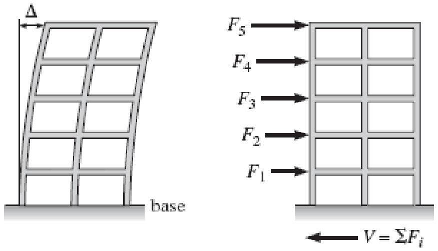
Category[a]	Nature of Occupancy	Seismic Factor I_E
I	**Building and other structures except those listed in Categories II, III, and IV**	**1.00**
II	**Buildings and other structures that represents a substantial hazard to human life in the event of failure, including, but not limited to:** • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures: elementary school, secondary school or day-care facilities with capacity greater than 250 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities • Jail or detention facilities • Any other occupancy with an occupant load greater than 5,000 • Power generating stations, water treatment for portable water, waste water treatment facilities, and other public utility facilities not included in category IV • Buildings and other structures not included in category IV containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.	**1.25**

Category[a]	Nature of Occupancy	Seismic Factor I_E
III	**Building and other structures designated as essential facilities including, but not limited to:** • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue, and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response • Power-generating stations and other public utility facilities required as emergency back-up facilities for category IV structures • Structures containing highly toxic material • Aviation control towers, air traffic control centers and emergency aircraft hangers • Buildings and other structures having critical national defense functions • Water treatment facilities required to maintain water pressure for fire suppression	**1.50**
IV	• **Buildings and other structures of low hazard to human life such as agricultural facilities and minor storage facilities**	**1.00**

Overturning

Ground motion can result in overturning of a structure. At any story, the increment of overturning moment in the story under consideration would have to be distributed to the various vertical force-resisting elements, in the same proportion as the distribution of the horizontal shear forces to these elements. The overturning moment at level x, M_x (kip-ft or kN-m), is determined from the following expression:

$$M_x = \tau \sum_{i=x}^{n} F_i(h_i - h_x)$$



where,

F_i = Portion of the seismic base shear, V, induced at level i

h_i and h_x = Height (ft or m) from the base to the level i or x

τ = overturning moment reduction factor

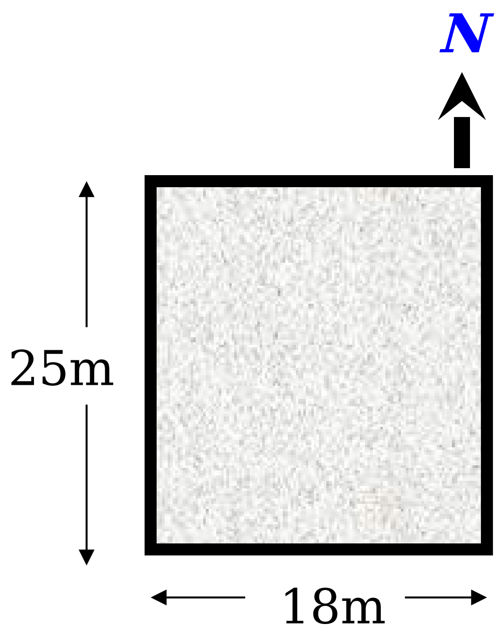
= 1.0 for the top 10 stories

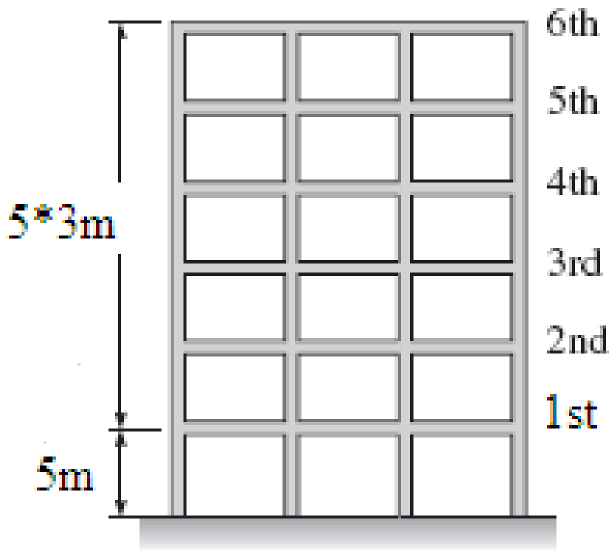
= 0.8 for the 20th story from the top and below

= values between 1.0 and 0.8 determined by a straight line interpolation for stories between the 20th and 10th stories below the top.

Example 1

- Determine the design seismic forces acting at each floor of the six-story office building in Figure below.
- *D.L=8kN/m2*
- *L.L=2.5kN/m2*
- *Shear wall system*





$$V = \frac{S_{D1} W}{T\left(R/I\right)}$$

$$S_{D1} = 0.10$$

$$W = 8(25)(18)(6) = 21600\ kN$$

$$T = 0.0488(20)^{\frac{3}{4}} = 0.462$$

$$R = 4\left(Shear\ Wall\right)$$

$$I = 1$$

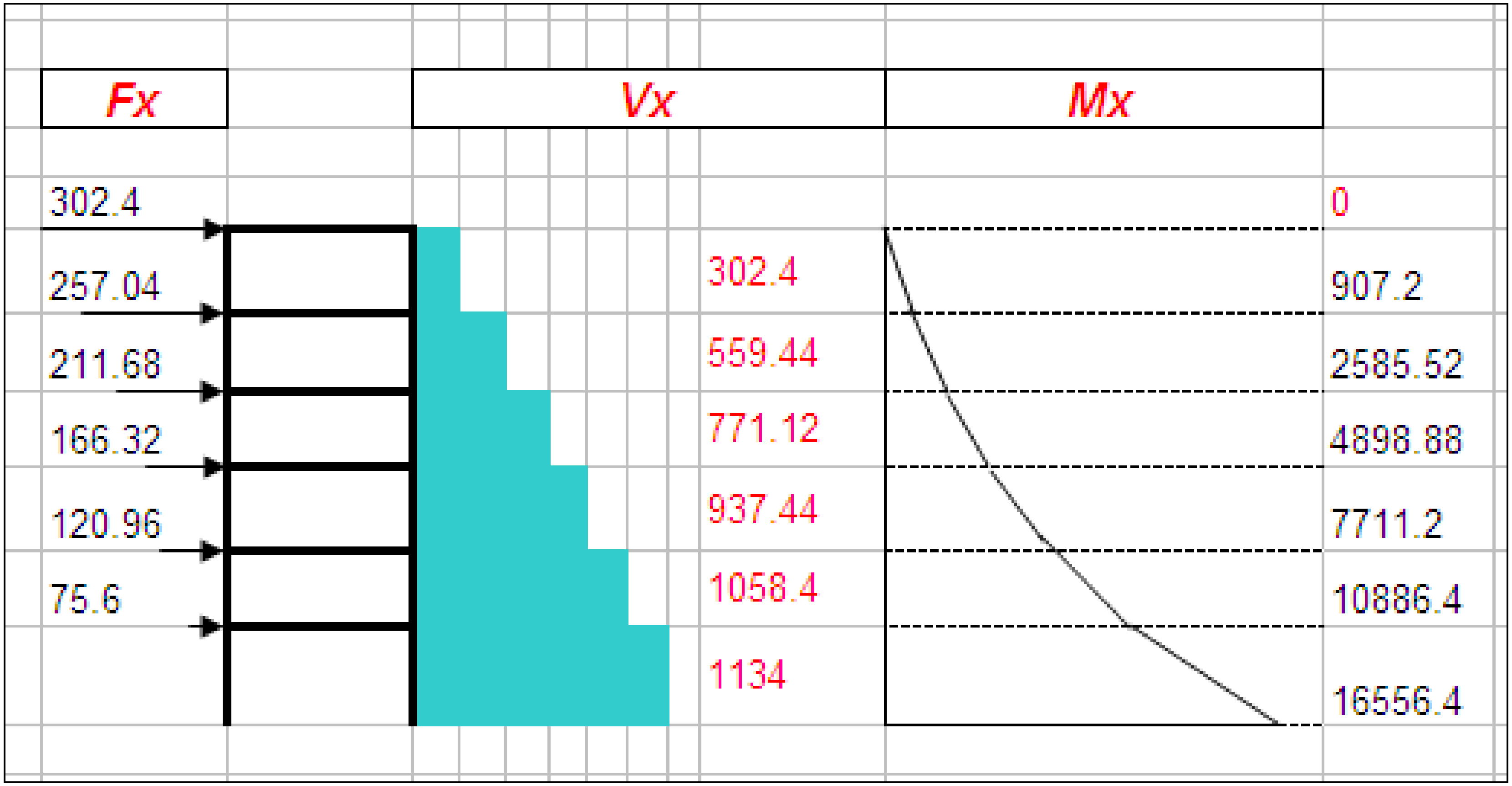
$$V = \frac{0.10\left(21600\right)}{0.462\left(\frac{4}{1}\right)} = 1169\ kN$$

$$V_{\min} = 0.044\left(IS_{DS}W\right) = 0.044(1)(0.21)(21600) = 200\ kN$$

$$V_{\max} = \frac{S_{DS}W}{R/I} = \frac{0.21\left(21600\right)}{4/1} = 1134\ kN$$

T=0.462 < 0.5 then **k=1**

Column	1	2	3(a)	3(b)	4	5	6	7	8
						$\frac{w_x h_x^k}{\sum_{i=1}^{6} w_i h_i^k}$			
	Slab	Wi	hi	h_{floor}	$W_i * h_i^K$		Fx	Vx	Mx
	6	3600	20		72000	0.27	302.4		0
				3				302.4	
	5	3600	17		61200	0.23	257.04		907.2
				3				559.44	
	4	3600	14		50400	0.19	211.68		2585.52
				3				771.12	
	3	3600	11		39600	0.15	166.32		4898.88
				3				937.44	
	2	3600	8		28800	0.11	120.96		7711.2
				3				1058.4	
	1	3600	5		18000	0.07	75.6		10886.4
	Base			5				1134	16556.4
Sum.		21600			270000				



:Note

Column 4 = column 3a * Column 2

((Fx = column 5 * (V = 1134)

Vx = cumulative column 6

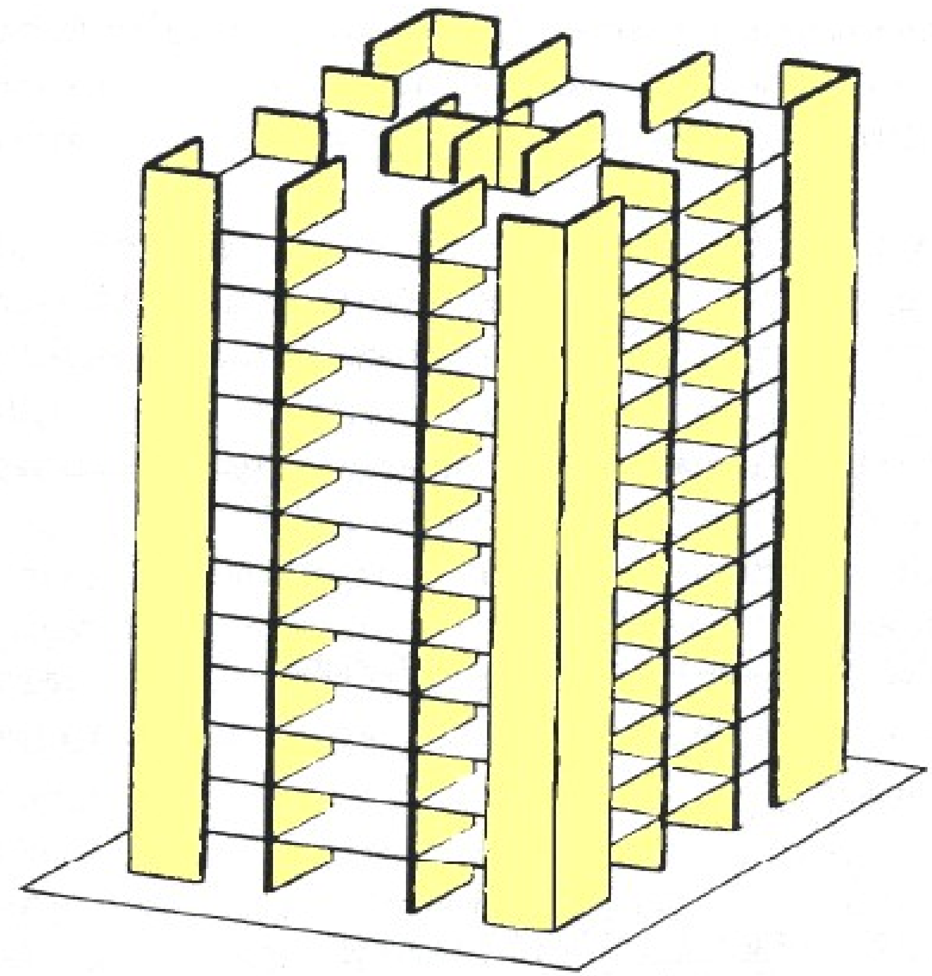
Mx = moment from Fx can calculated from shear Area

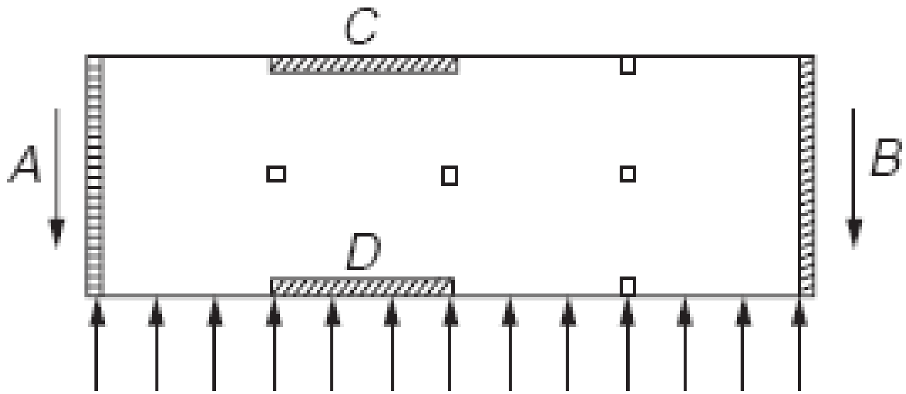
Shear Wall Design

Introduction

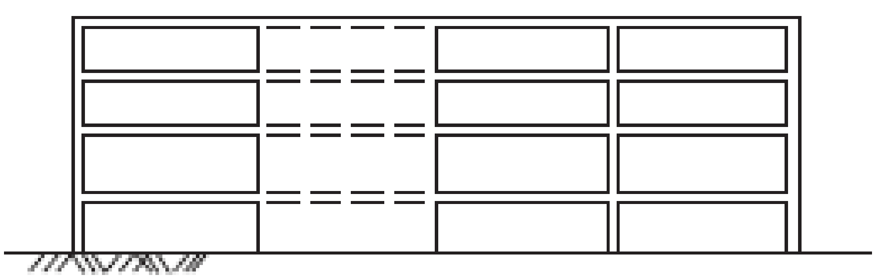
Shear walls

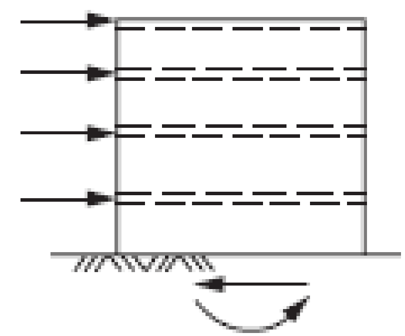
provide a high in-plane stiffness and strength for both lateral and gravity loads, and are ideally suitable for tall buildings, especially those conceived in reinforced concrete. Tall buildings designed to carry the entire lateral loading through shear walls can be economical to heights of around 40 stories. Taller structures should

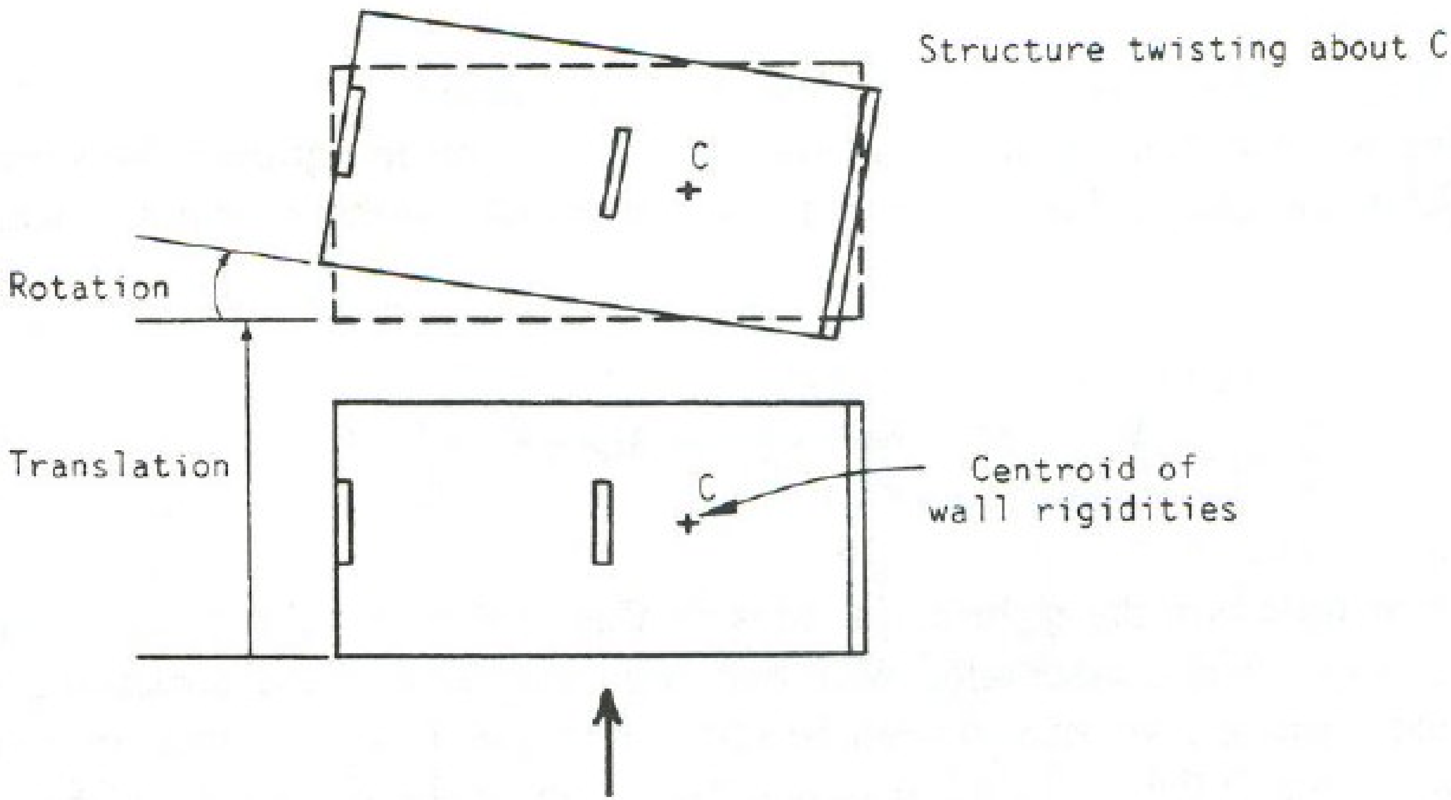




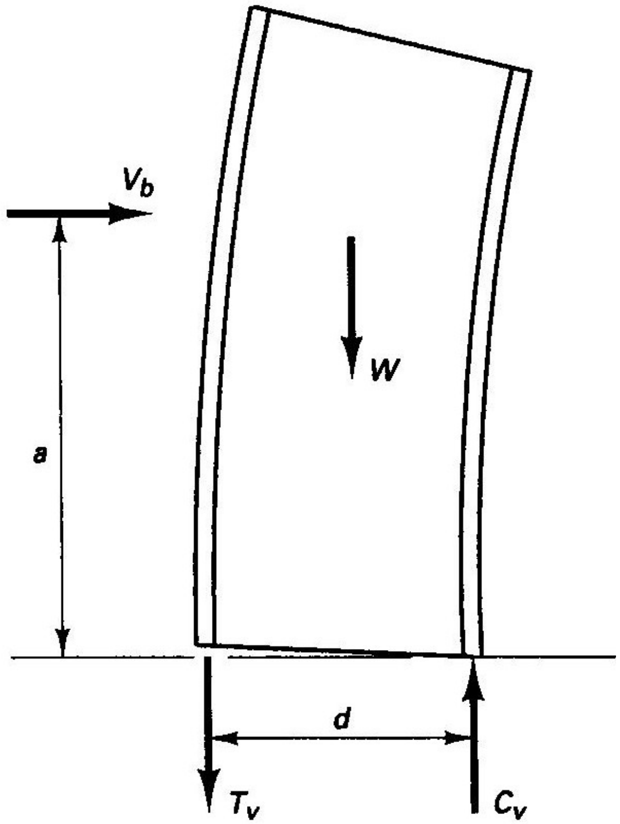
(a)

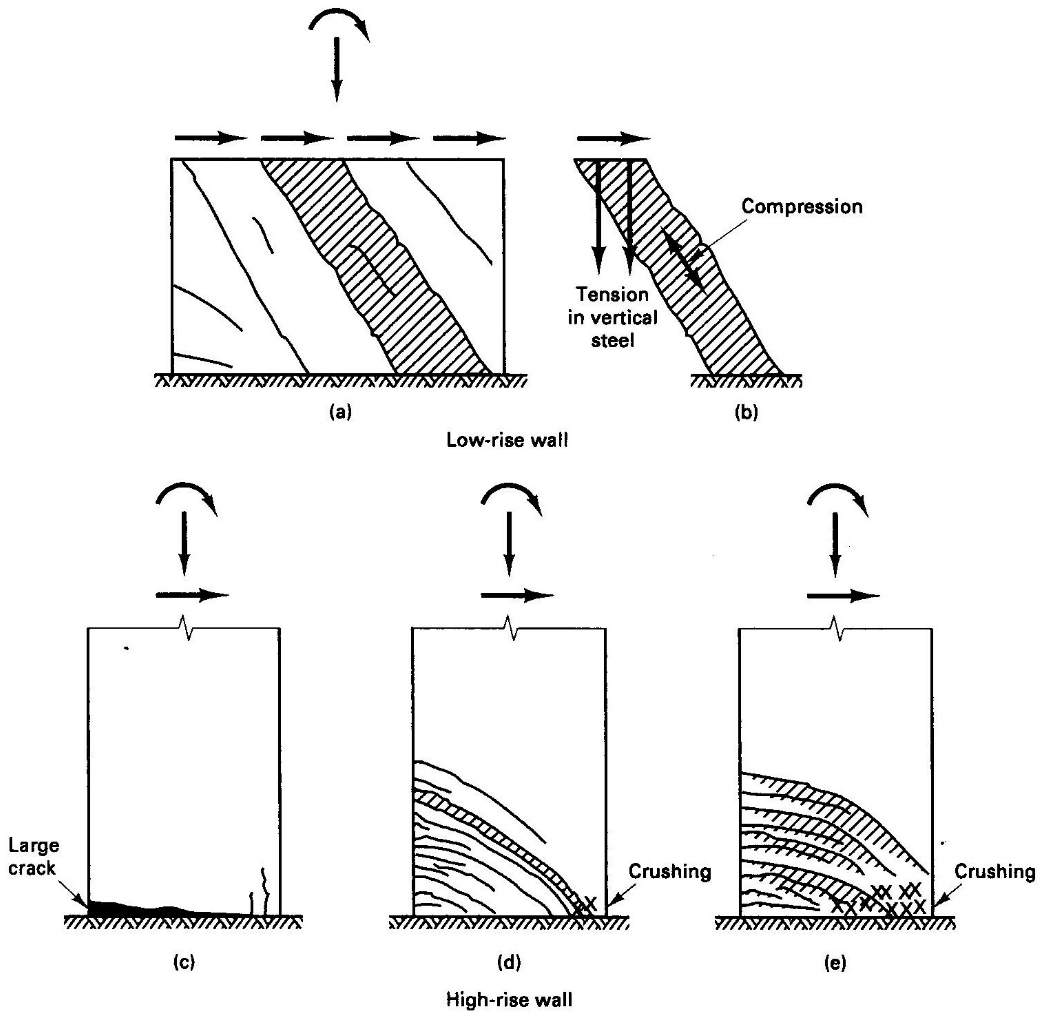





Structure twisting about C
C
Rotation
Translation
C
Centroid of
wall rigidities

Shear Wall design





Shear Wall Design Steps

1- Calculate External Load

$$M_u$$

$$V_u$$

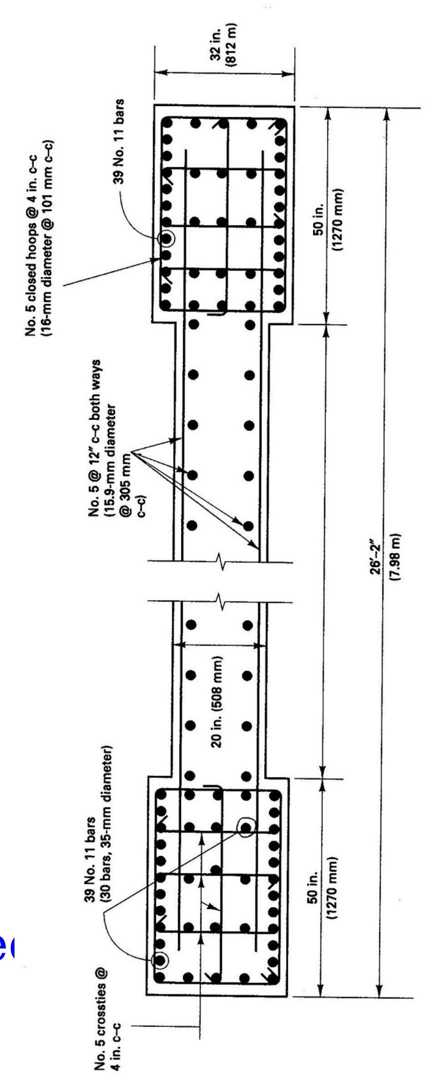
$$P_u$$

2- boundary element check

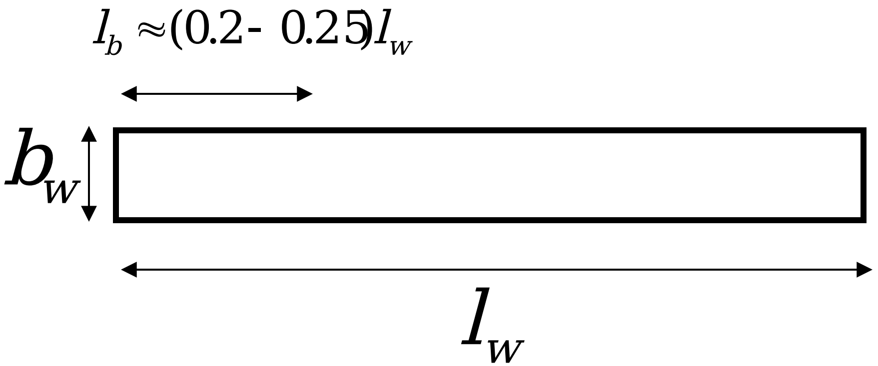
$$I_g = \frac{bh^3}{12} = \frac{b_w l_w^3}{12}$$

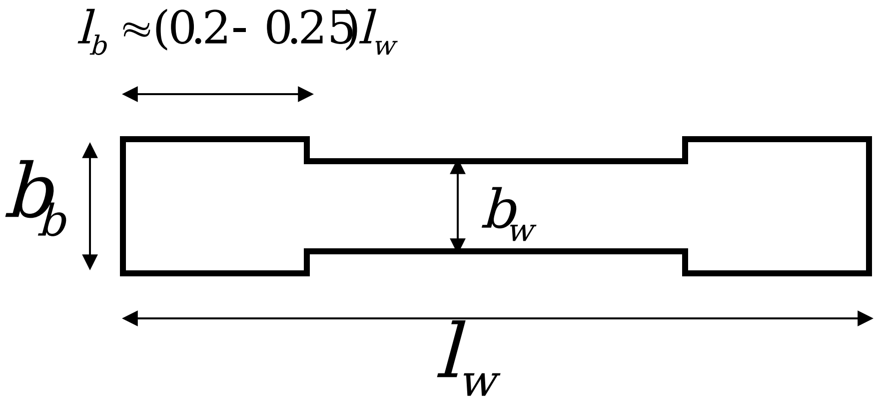
$$f_c = \frac{P}{A} \pm \frac{MC}{I}$$

if $f_c < 0.2 f'_c$ Then boundary elements are not require



Then choose the one of:





3- Longitudinal Reinforcement

At least two curtains of reinforcement are needed in the wall if the in-plane factored shear exceed a value of

$$\frac{A_{cv}\sqrt{f_c^{'}}}{6}$$

$$A_{cv} = l_w b_w$$

$$\left\{ if \ \frac{h_w}{l_w} > 2 \right\} \Rightarrow \ V_u = \phi V_n = \phi \ A_{cv}\left(\frac{\sqrt{f_c^{'}}}{6} + \rho_n f_y \right)$$

$$\left\{ if \ \frac{h_w}{l_w} = 1.5 \right\} \Rightarrow \ V_u = \phi V_n = \phi \ A_{cv}\left(\frac{\sqrt{f_c^{'}}}{4} + \rho_n f_y \right)$$

$$\phi = 0.6$$

$$V_{n(\max)} = \frac{4A_{cv}\sqrt{f_c^{'}}}{6}$$

Minimum reinforcement

$$if\ V_u > \frac{A_{cv}\sqrt{f'_c}}{6}$$

$$\rho_v = 0.0025$$

$$\rho_h = 0.0025$$

$$if\ V_u < \frac{A_{cv}\sqrt{f'_c}}{6}$$

$$\text{for bar} \leq \phi 16$$

$$\rho_v = 0.0012$$

$$\rho_h = 0.0020$$

$$\text{for bar} > \phi 16$$

$$\rho_v = 0.0015$$

$$\rho_h = 0.0025$$

4- Verify adequacy of shear wall section at its base under combined axial load and bending moment

M_u

P_u

$\frac{M_u}{A_g l_w}, \frac{P_u}{A_g} \rightarrow$ interaction diagram

ρ

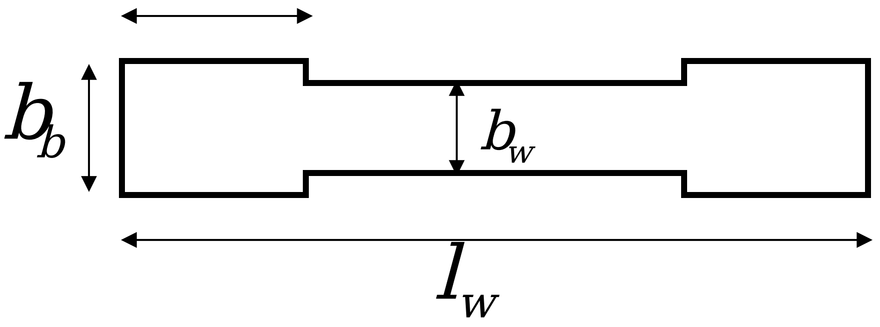
$A_s = \rho A_g$

$A_{sb} = A_s - A_{sv}$

A_{sb} = area of reinforcement in boundary element

A_{sv} = area of reinforcement in $(l_w - 2l_b)$

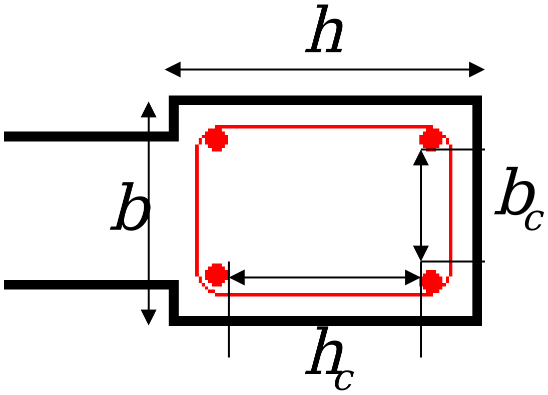
$l_b \approx (0.2 - 0.25) l_w$



5- Boundary element transverse reinforcement

$$A_{sh} \geq 0.09 S h_c \frac{f_c'}{f_{yh}}$$

$$A_{sh} \geq 0.3 S h_c \left(\frac{A_g}{A_{ch}} - 1 \right) \frac{f_c'}{f_{yh}}$$

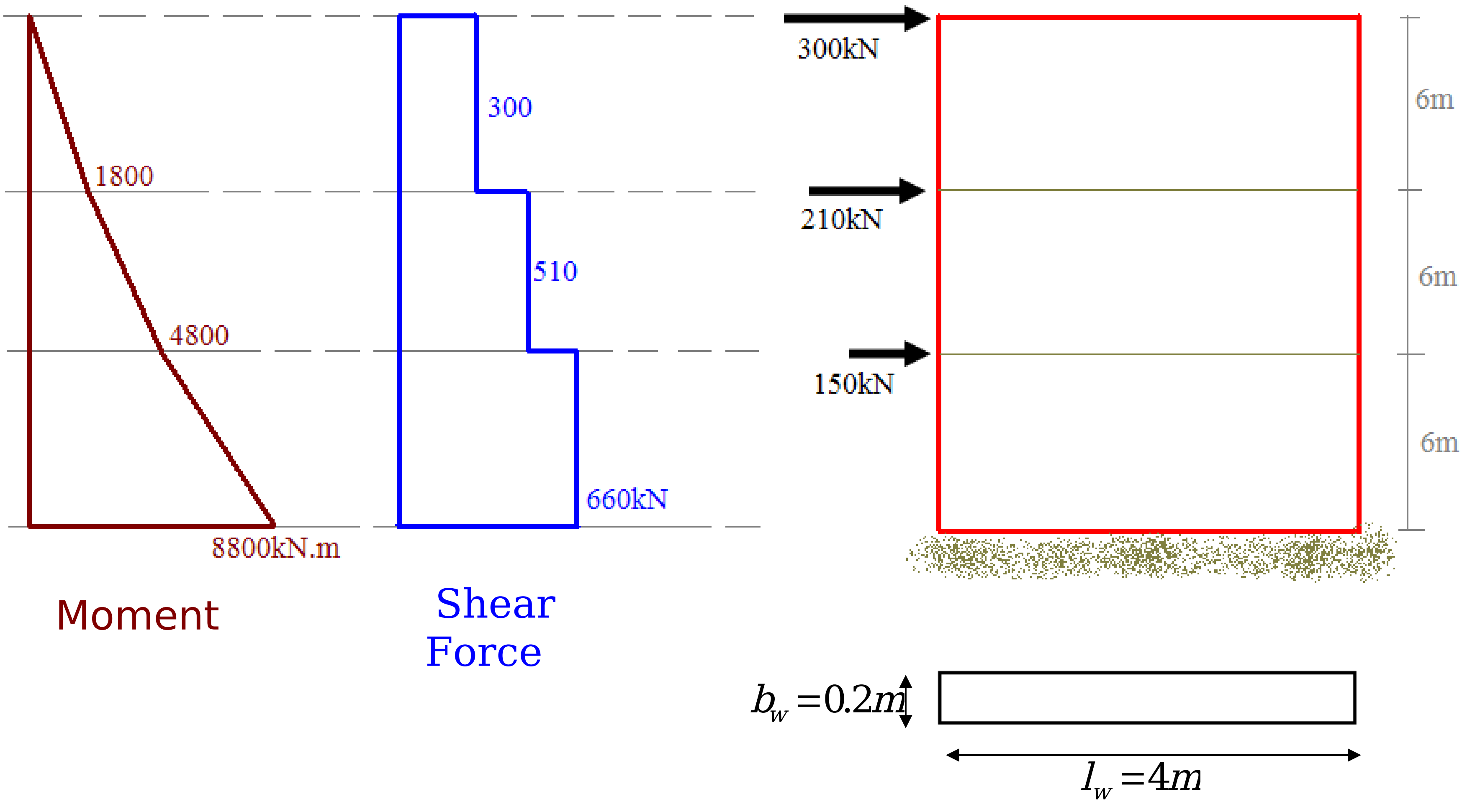


You must check it in two dimension

Example 1

Design the following shear wall

1- Calculate External Load

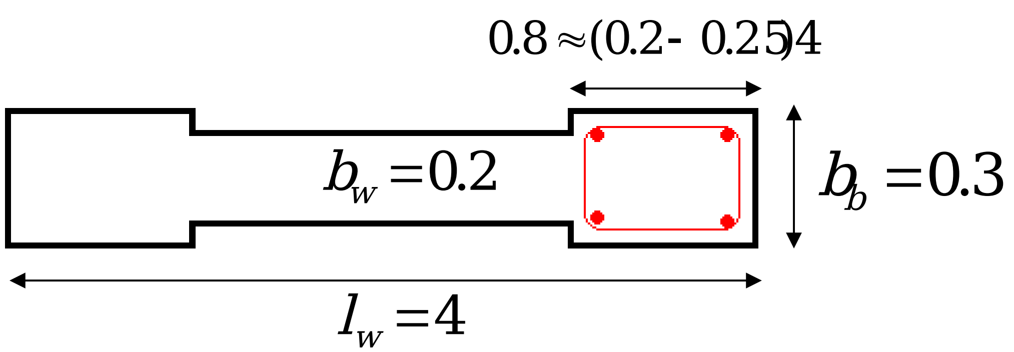


2- boundary element check

$$I_g = \frac{b_w l_w^3}{12} = \frac{0.2(4)^3}{12} = 1.067$$

$$f_c = \left(\frac{1500}{0.2\times4} + \frac{8800\times2}{1.067}\right) * 10^{-6} = 18.4 MN/m^2 > 0.2(30) = 6 Mpa$$

Boundary element required



3- Longitudinal Reinforcement

At least two curtains of reinforcement are needed in the wall if the in-plane factored shear exceed a value of

$$\frac{A_{cv}\sqrt{f_c'}}{6} = \frac{200(4000)\sqrt{30}}{6} = 730.3\,kN > (V_u = 660\,kN)$$

Minimum reinforcement

$$\because\ V_u < \frac{A_{cv}\sqrt{f_c'}}{6}$$

$$for\ bar \leq \phi 16$$

$$\rho_v = 0.0012 \Rightarrow A_{sv} = 0.0012(1000)(200) = 240\,mm^2 = 2.4\,cm^2$$

$$S_{max} = 45\,cm$$

$$use \rightarrow \phi 12 @ 25\,cm\ (each\ direction)$$

$$\rho_h = 0.0020 \Rightarrow A_{sv} = 0.002(1000)(200) = 400\,mm^2 = 4\,cm^2$$

$$S_{max} = 45\,cm$$

$$use \rightarrow \phi 12 @ 25\,cm\ (each\ direction)$$

4- Verify adequacy of shear wall section at its base under combined axial load and bending moment

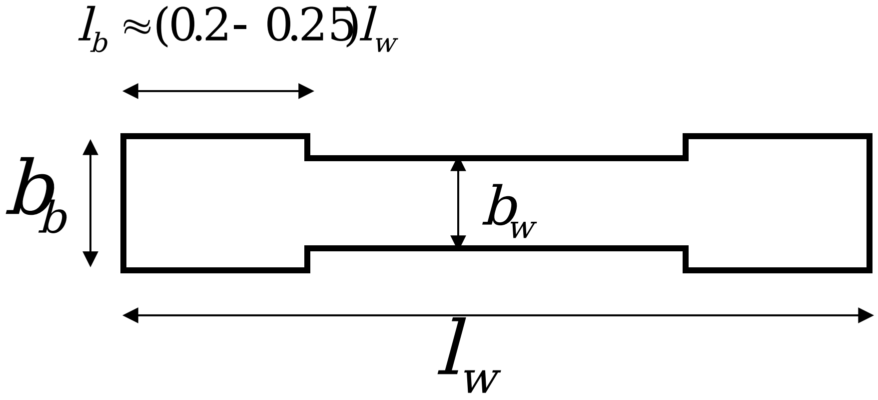
$$M_u = 8800 \times 10^6 \, N.m$$

$$P_u = 1500 \times 10^3 \, N$$

$$A_g = \{4 - 2 \times 0.8\} \times 0.2 + 2(0.8 \times 0.3) = 1 m^2 = 1 \times 10^6 mm^2$$

$$\frac{M_u}{A_g l_w} = \frac{8800 \times 10^6}{(1 \times 10^6)4000} = 2.2 MPa = 0.31 ksi$$

$$\frac{P_u}{A_g} = \frac{1500 \times 10^3}{1 \times 10^6} = 1.5 MPa = 0.21 ksi$$



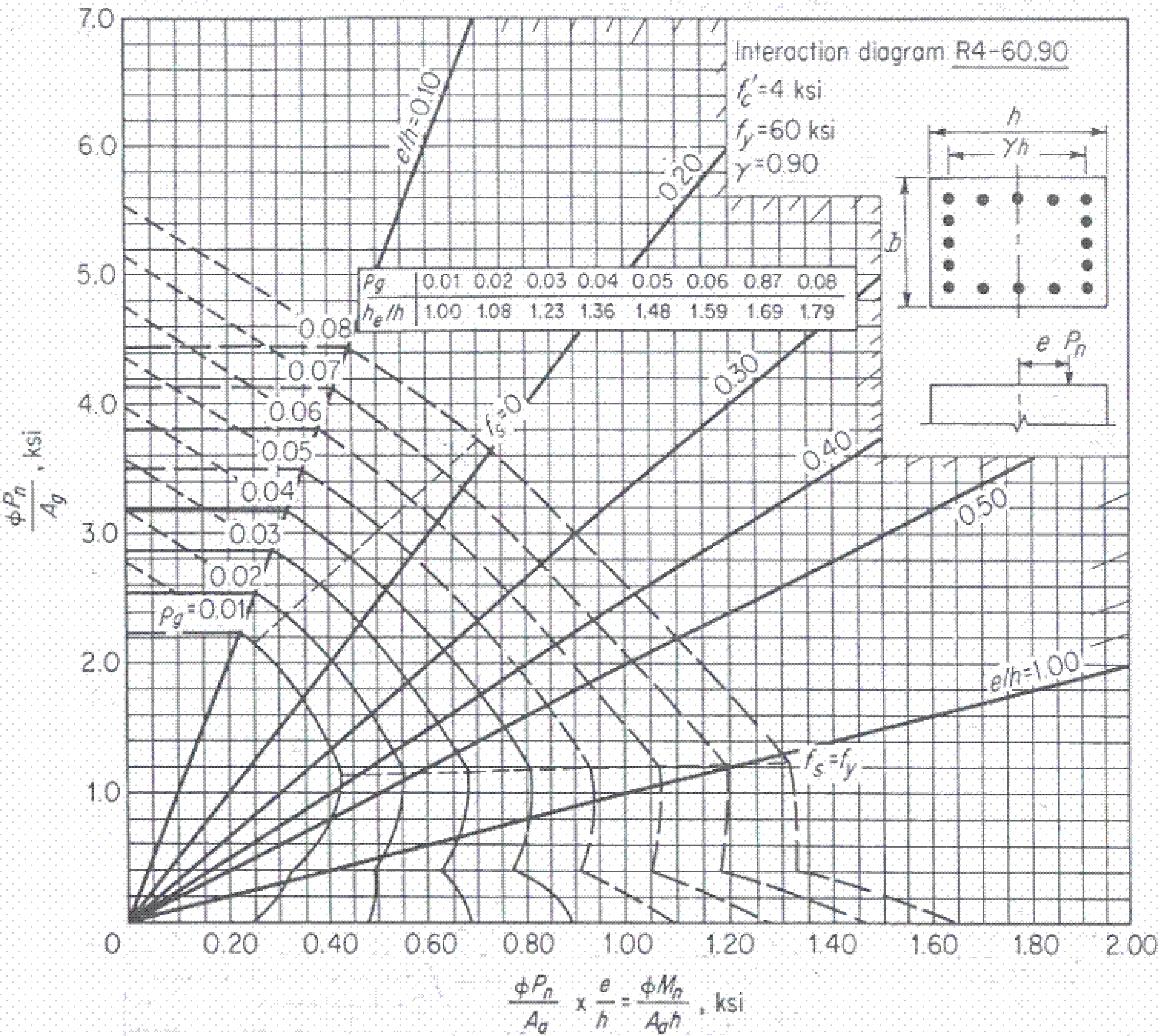
$$\gamma = 0.9$$

$$\rho = 0.01$$

$$A_s = \rho A_g = 0.01(1 \times 10^6) = 10000 mm^2 = 100 cm^2$$

$$A_{sb} = A_s - A_{sv} = 100 - \left(\frac{2.6}{0.25} \times 2 \times 1.13\right) = 76.5 cm^2$$

$38.25 cm^2$ for each boundary element use $16 \phi 18$



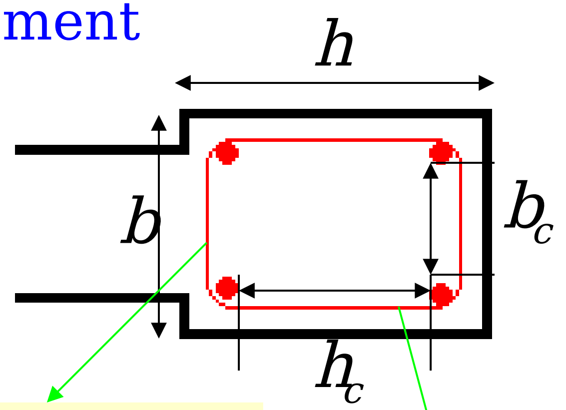
Interaction diagram R4-60.90
f'_c=4 ksi
f_y=60 ksi
γ=0.90
h
γh
b
e P_n
ρ_g 0.01 0.02 0.03 0.04 0.05 0.06 0.87 0.08
h_e/h 1.00 1.08 1.23 1.36 1.48 1.59 1.69 1.79
e/h=0.10
0.20
0.30
0.40
0.50
e/h=1.00
f_s=0
$f_s=f_y$
ρ_g=0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
$\frac{\phi P_n}{A_g}$, ksi
$\frac{\phi P_n}{A_g} \times \frac{e}{h} = \frac{\phi M_n}{A_g h}$, ksi

5- Boundary element transverse reinforcement

$$A_{sh} \geq 0.09 S h_c \frac{f_c^{'}}{f_{yh}}$$

$$A_{sh} \geq 0.3 S h_c \left(\frac{A_g}{A_{ch}} - 1 \right) \frac{f_c^{'}}{f_{yh}}$$

Check short direction



Check short direction

Check long direction

$$S = 120 mm$$

$$h_c = 80 - 2(3 + 1.8) = 70.4 cm$$

$$b_c = 30 - 2(3 + 1.8) = 20.4 cm$$

$$A_{sh} \geq 0.09 S h_c \frac{f_c^{'}}{f_{yh}} = 0.09(120)(704)\frac{30}{420} = 543.2 mm^2 = 5.4 cm^2$$

Check long direction

$$S = 120\,mm$$

$$h_c = 80 - 2(3 + 1.8) = 70.4\,cm$$

$$b_c = 30 - 2(3 + 1.8) = 20.4\,cm$$

$$A_{sh} \geq 0.09 S b_c \frac{f_c^{'}}{f_{yh}} = 0.09(120)(204)\frac{30}{420} = 160\,mm^2 = 1.6\,cm^2$$

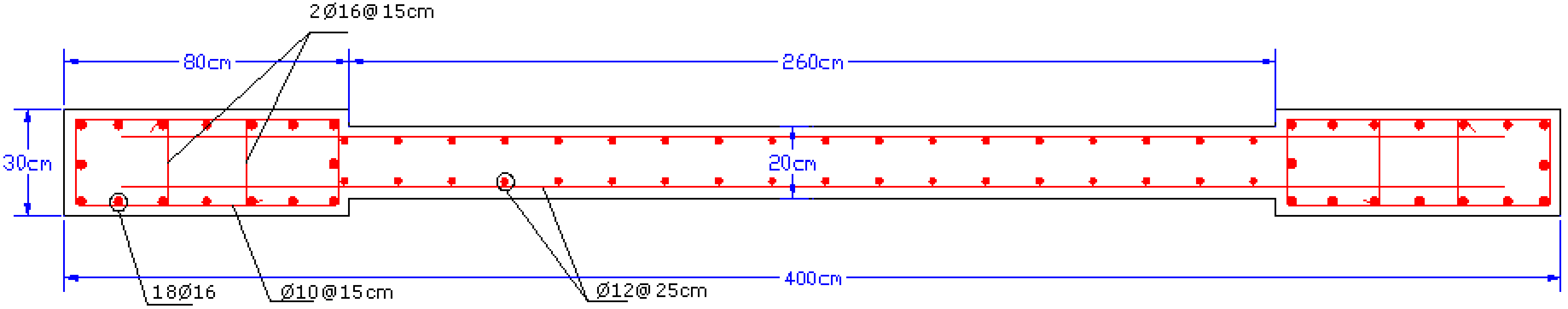
$$A_{sh} = 1.6\,cm^2$$

short direction use 2 legs close hoop $\phi 10$ & 2 internal legs $\phi 16$

$$= 2(0.79) + 2(2.01) = 5.6\,cm^2$$

short direction use 2 legs close hoop $\phi 10$

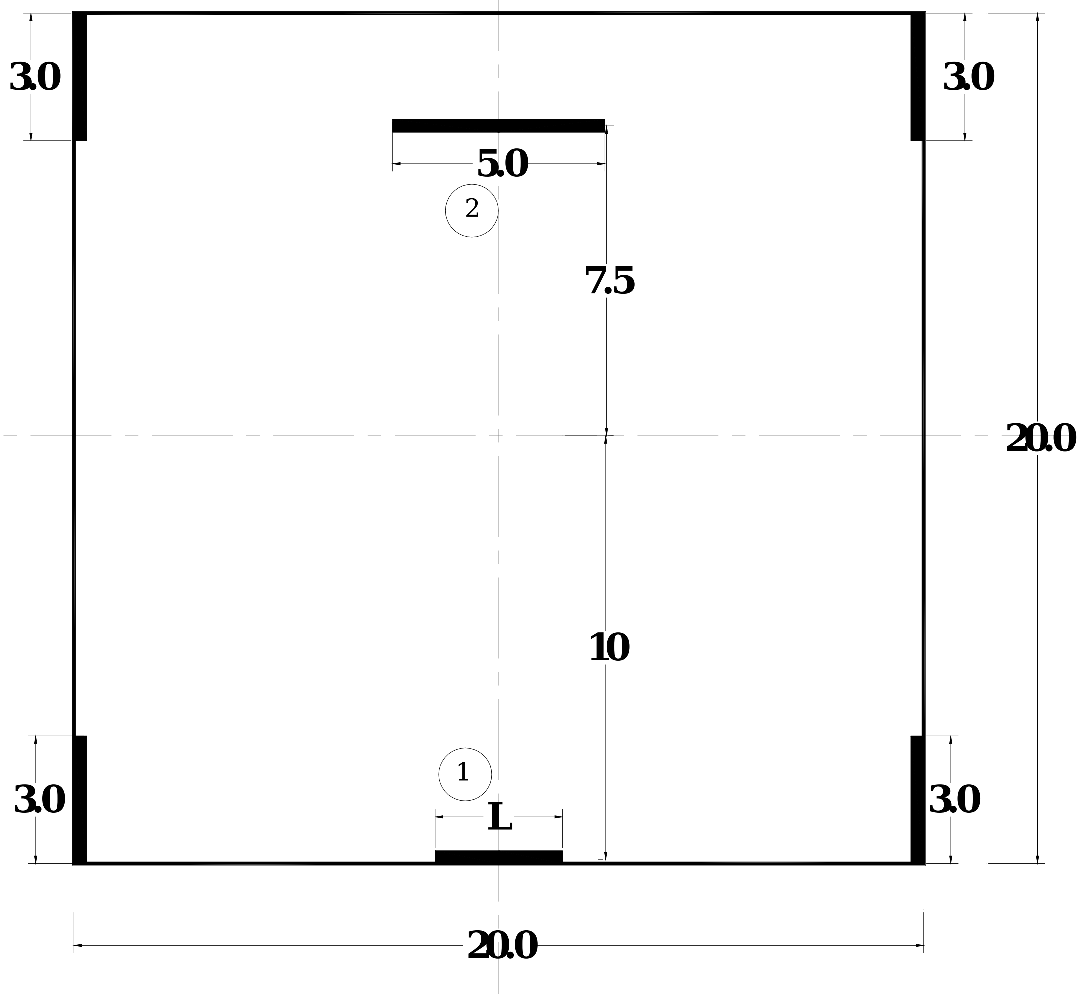
$$= 2(0.79) = 1.6\,cm^2$$

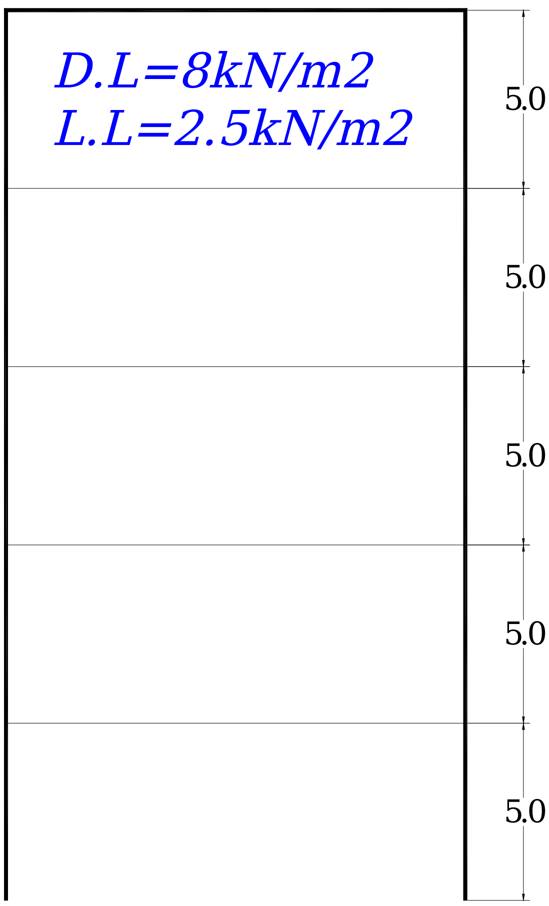


2Ø16@15cm
80cm
260cm
30cm
20cm
400cm
18Ø16
Ø10@15cm
Ø12@25cm

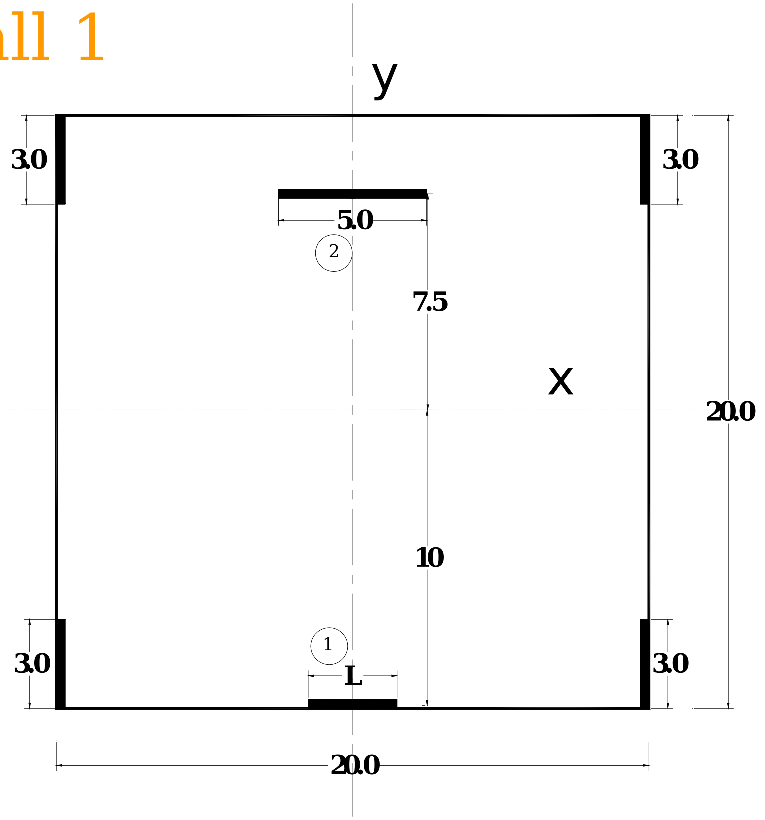
Design Example

Design Shear wall 1 & 2 in the figure bel
Gaza City





1- calculate the length of shear wall 1



$$\bar{y} = \sum_{i=1}^{n} \frac{I_i y_i}{\sum I_i}$$

$$I_2 = \frac{5^3(0.2)}{12} = 2.08,$$

$$y_2 = 7.5$$

$$I_1 = \frac{L^3(0.2)}{12} = 0.0166L^3,$$

$$y_1 = -10$$

$$\bar{y} = \sum_{i=1}^{n} \frac{I_i y_i}{\sum I_i} = \frac{I_1 y_1 + I_2 y_2}{I_1 + I_2} = \frac{2.08(7.5) + 0.0166L^3(-10)}{I_1 + I_2} = 0$$

$$2.08(7.5) - 0.0166L^3(10) = 0$$

$$L_1 = 4.5m$$

2- Seismic Shear for the total building

$$V = \frac{S_{D1} W}{T\left(R/I\right)}$$

$$S_{D1} = 0.10$$

$$W = 8(20)(20)(5) = 16000\ kN$$

$$T = 0.0488(25)^{\frac{3}{4}} = 0.55$$

$$R = 4\ (Shear\ Wall)$$

$$I = 1.25$$

$$V = \frac{0.10(16000)}{0.55\left(\frac{4}{1.25}\right)} = 909\ kN$$

$$V_{\min} = 0.044(I S_{DS} W) = 0.044(1.25)(0.21)(16000) = 185.2\ kN$$

$$V_{\max} = \frac{S_{DS} W}{R/I} = \frac{0.21(16000)}{4/1.25} = 1050\ kN$$

For the total Building

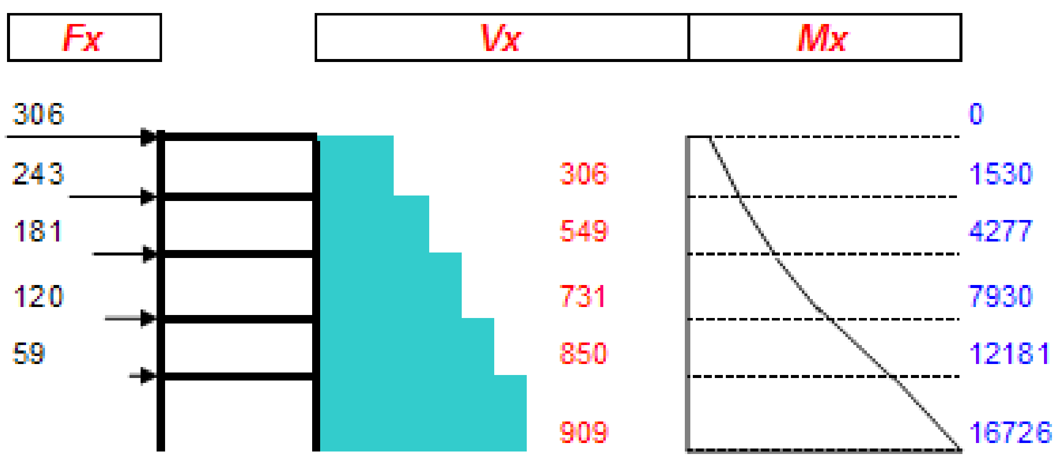
$$T=0.55>0.5 \quad k=1+\frac{T-0.5}{2}=1.025$$

Column	1	2	3(a)	3(b)	4	5	6	7	8
	Slab	Wi	hi	h floor	$W_i * h_i^K$	$\frac{w_x h_x^k}{\sum_{i=1}^{6} w_i h_i^k}$	Fx	Vx	Mx
	5	3200	25		86704	0.34	306		0
				5				306	
	4	3200	20		68977	0.27	243		1530
				5				549	
	3	3200	15		51362	0.20	181		4277
				5				731	
	2	3200	10		33896	0.13	120		7930
				5				850	
	1	3200	5		16657	0.06	59		12181
	Base			5				909	16726
Sum.		16000			257596				

Column 4 = column 3a * Column 2

Fx = column 5 * (V = 909)

Vx = cumulative column 6



V = 909 kN

M =16726 kN.m

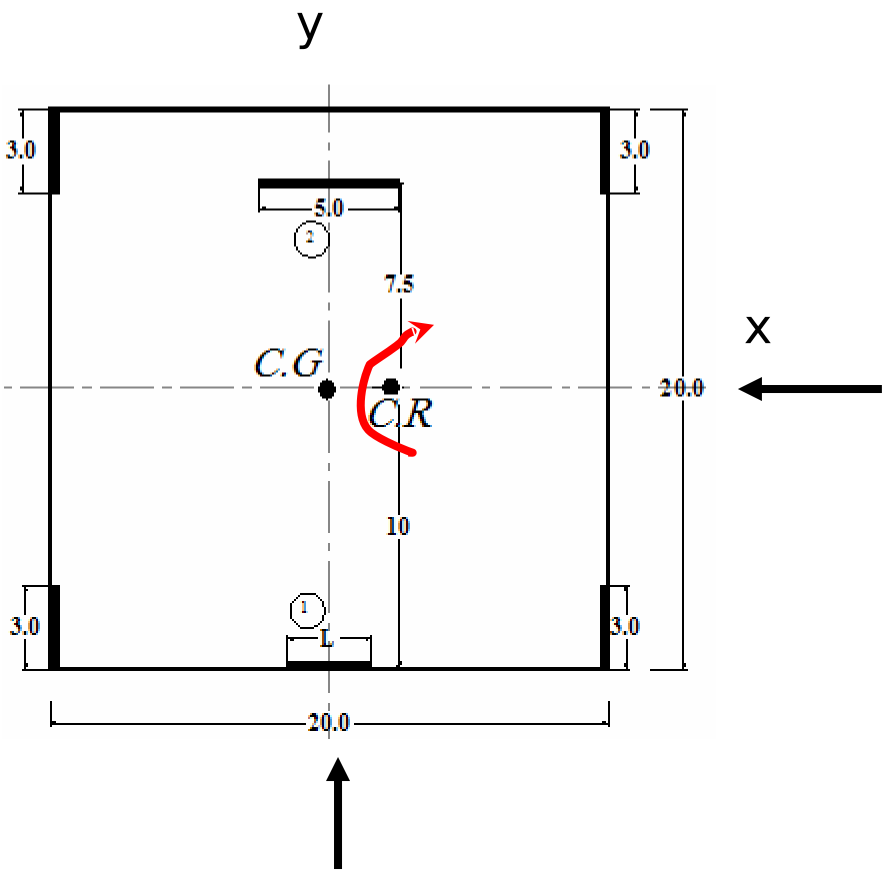
For shear walls

$$V_i = (a+b)\times V$$

$$M_i = (a+b)\times M$$

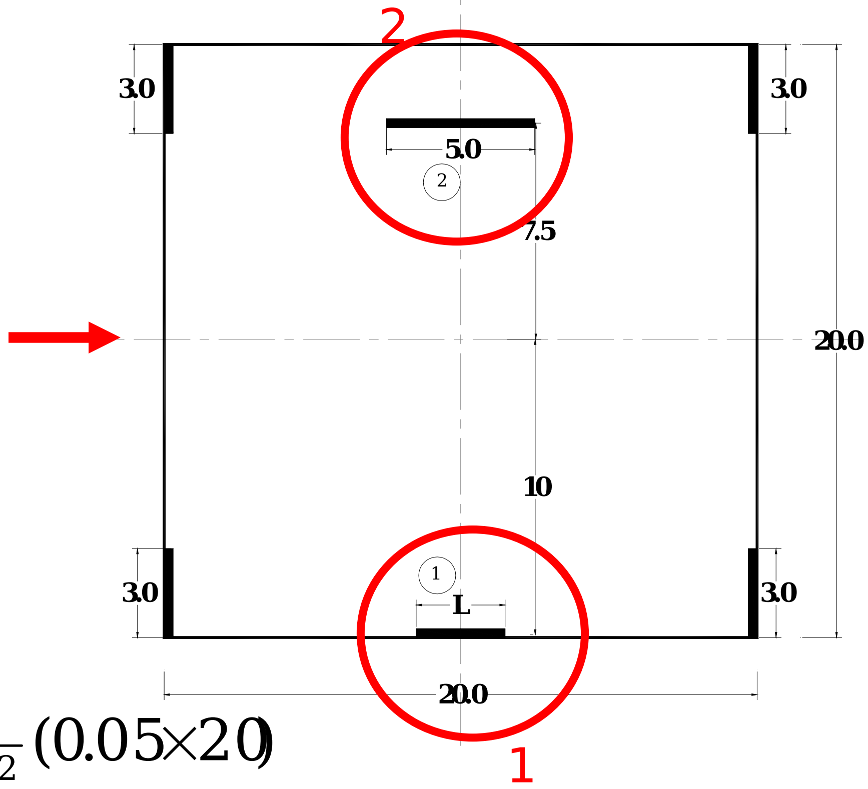
$$a = \frac{I_i}{\sum_{i=1}^{n} I_i}$$

$$b = \frac{I_i y_i}{\sum\left(I_{iy} y_i^2 + I_{ix} x_i^2\right)}\left(C.R + 0.05(L)\right)$$



In this example without neglect the effect of twist force

For shear wall No. 1

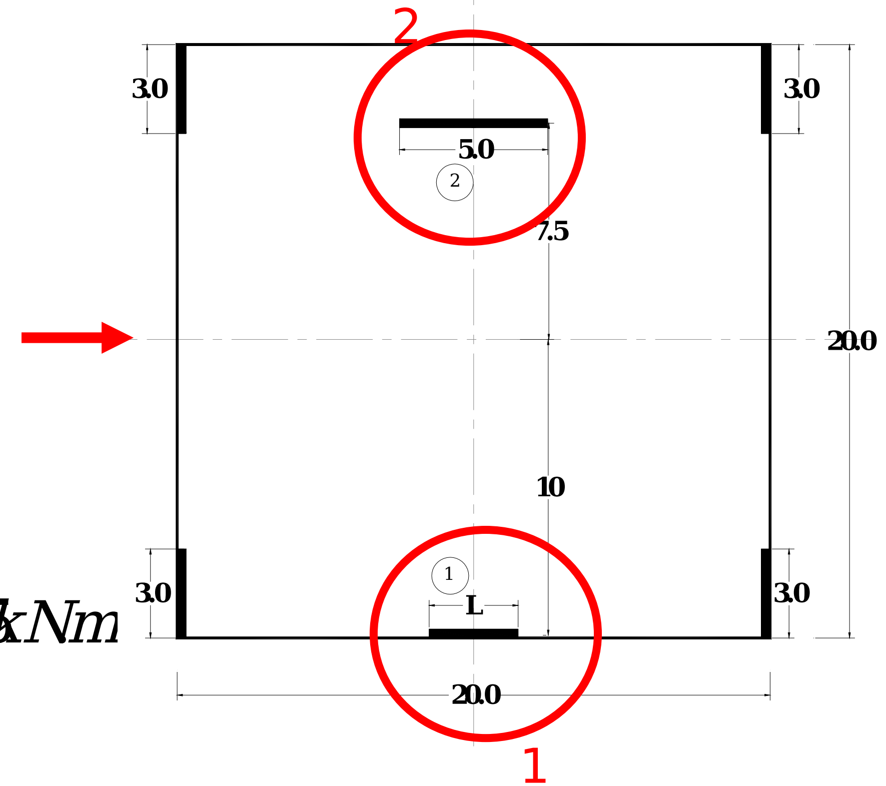


$$a=\frac{I_i}{\sum_{i=1}^{n} I_i}=\frac{\frac{0.2\times 4.5^3}{12}}{\frac{0.2\times 4.5^3}{12}+\frac{0.2\times 5^3}{12}}=0.42$$

$$b=\frac{\frac{0.2\times 4.5^3}{12}(10)}{\frac{0.2\times 4.5^3}{12}(10)^2+\frac{0.2\times 5^3}{12}(7.5)^2+4\times\frac{0.2\times 3^3}{12}(10)^2}(0.05\times 20)$$

$$b=0.024$$

3- In this example we will neglect the effect of twist force



For shear wall No. 1

$$a = \frac{I_i}{\sum_{i=1}^{n} I_i} = \frac{\frac{0.2 \times 4.5^3}{12}}{\frac{0.2 \times 4.5^3}{12} + \frac{0.2 \times 5^3}{12}} = 0.42$$

$$V_i = (a) \times V = 0.42 \times 909 = 382\ kN$$

$$M_i = (a) \times M = 0.42 \times 16726 = 7025\ kN.m$$

For shear wall No. 2

$$a = 0.58$$

$$V_i = (a) \times V = 0.58 \times 909 = 528\ kN$$

$$M_i = (a) \times M = 0.58 \times 16726 = 9701\ kN.m$$

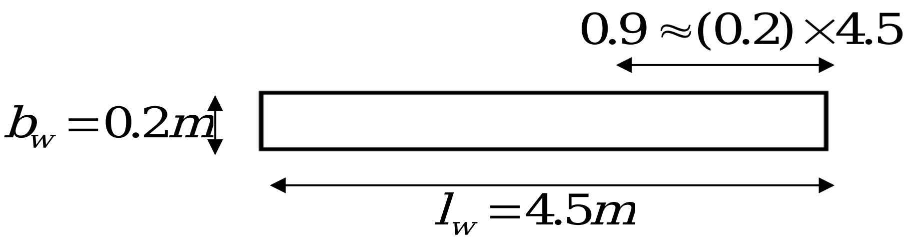
4- Shear wall design

boundary element check

$$I_g = \frac{b_w l_w^3}{12} = \frac{0.2(4.5)^3}{12} = 1.519$$

$$f_c = \left(\frac{1500}{0.2 \times 4.5} + \frac{7025 \times 2.25}{1.519} \right) * 10^{-3} = 12.072\, MN/m^2 > 0.2(30) = 6\, Mpa$$

Boundary element required



Longitudinal Reinforcement

At least two curtains of reinforcement are needed in the wall if the in-plane factored shear exceed a value of

$$\frac{A_{cv}\sqrt{f_c'}}{6} = \frac{200(4500)\sqrt{30}}{6} = 821.6\,kN > (V_u = 382\,kN)$$

Minimum reinforcement

$$\because \; V_u < \frac{A_{cv}\sqrt{f_c'}}{6}$$

$\text{for bar} \le \phi 16$

$$\rho_v = 0.0012 \Rightarrow A_{sv} = 0.0012(1000)(200) = 240\,mm^2 = 2.4\,cm^2$$

$$S_{\max} = 45\,cm$$

$$use \to \phi 12 @ 25\,cm \;(\text{each direction})$$

$$\rho_h = 0.0020 \Rightarrow A_{sv} = 0.002(1000)(200) = 400\,mm^2 = 4\,cm^2$$

$$S_{\max} = 45\,cm$$

$$use \to \phi 12 @ 25\,cm \;(\text{each direction})$$

Verify adequacy of shear wall section at its base under combined axial load and bending moment

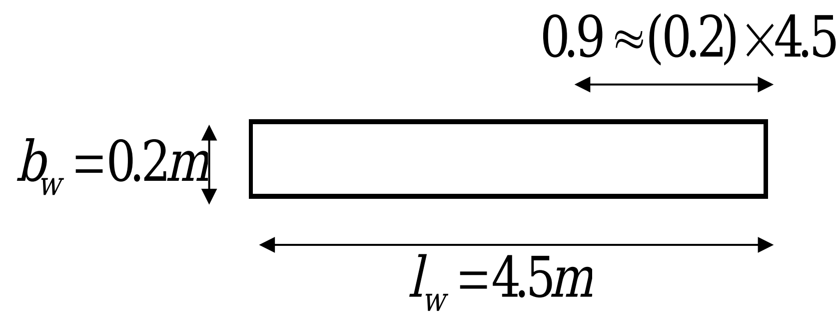
$$M_u = 8800\times10^6\ N.m$$

$$P_u = 1500\times10^3\ N$$

$$A_g = 4.5\times0.2 = 0.9m^2 = 0.9\times10^6\ mm^2$$

$$\frac{M_u}{A_g l_w} = \frac{7025\times10^6}{(0.9\times10^6)4500} = 1.73MPa = 0.25ksi$$

$$\frac{P_u}{A_g} = \frac{1500\times10^3}{0.9\times10^6} = 1.66MPa = 0.24ksi$$



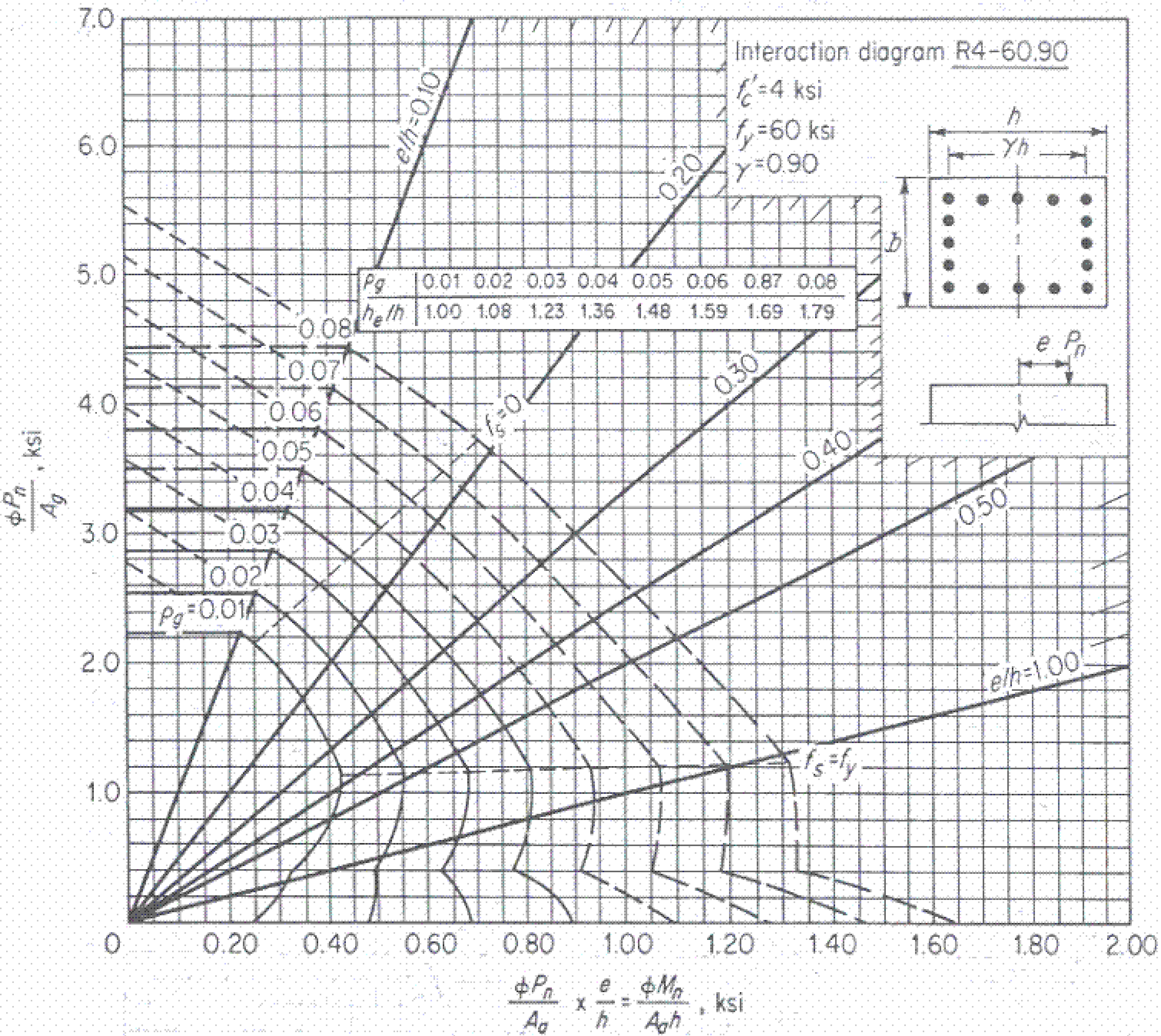
$$\gamma = 0.9$$

$$\rho = 0.01$$

$$A_s = \rho A_g = 0.01(0.9\times10^6) = 9000mm^2 = 90cm^2$$

$$A_{sb} = A_s - A_{sv} = 90 - \left(\frac{4.5-2(0.9)}{0.25}\times2\times1.13\right) = 65.6cm^2$$

$32.8cm^2$ for each boundary element use $16\phi16$

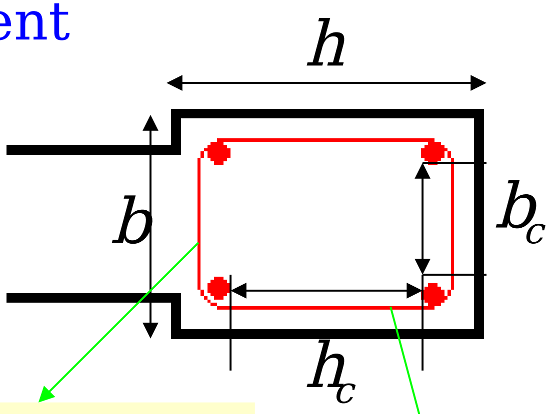

Interaction diagram R4-60.90
f_c'=4 ksi
f_y=60 ksi
γ=0.90
h
γh
b
e P_n
ρ_g | 0.01 0.02 0.03 0.04 0.05 0.06 0.87 0.08
h_e/h | 1.00 1.08 1.23 1.36 1.48 1.59 1.69 1.79
e/h=0.10
0.20
0.30
0.40
0.50
e/h=1.00
f_s=0
$f_s=f_y$
ρ_g=0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00
$\frac{\phi P_n}{A_g}$, ksi
$\frac{\phi P_n}{A_g} \times \frac{e}{h} = \frac{\phi M_n}{A_g h}$, ksi

Boundary element transverse reinforcement

$$A_{sh} \geq 0.09 S h_c \frac{f'_c}{f_{yh}}$$

$$A_{sh} \geq 0.3 S h_c \left(\frac{A_g}{A_{ch}} - 1 \right) \frac{f'_c}{f_{yh}}$$

Check short direction



Check short direction

Check long direction

$$S = 100 mm$$

$$h_c = 90 - 2(3 + 1.8) = 80.4 cm$$

$$b_c = 20 - 2(3 + 1.8) = 10.4 cm$$

$$A_{sh} \geq 0.09 S h_c \frac{f'_c}{f_{yh}} = 0.09(100)(804)\frac{30}{420} = 516.9 mm^2 = 5.2 cm^2$$

Check long direction

$$S = 100\,mm$$

$$h_c = 90 - 2(3 + 1.8) = 80.4\,cm$$

$$b_c = 20 - 2(3 + 1.8) = 10.4\,cm$$

$$A_{sh} \geq 0.09\,S\,h_c \frac{f_c'}{f_{yh}} = 0.09(100)(104)\frac{30}{420} = 66.8\,mm^2 = 0.7\,cm^2$$

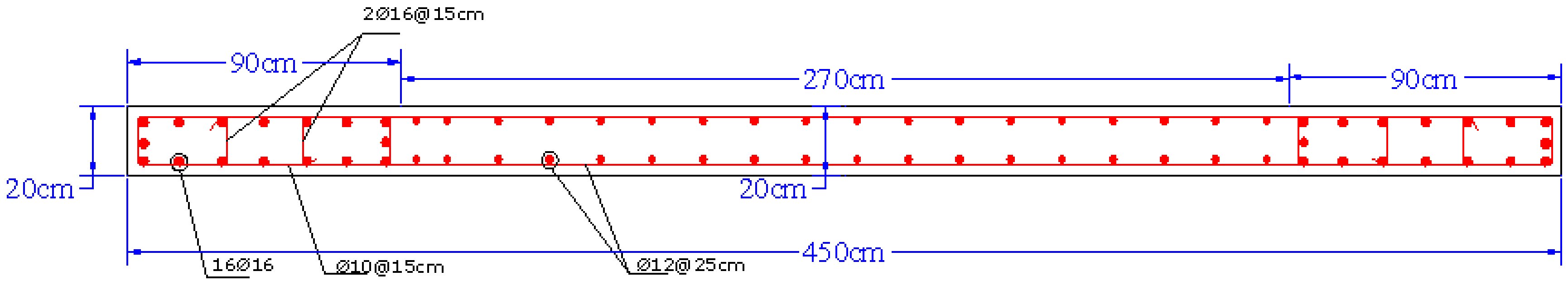
short direction use <u>2 legs</u> close hoop $\phi 10$ & <u>2 internal legs</u> $\phi 16$

$$= 2(0.79) + 2(2.01) = 5.6\,cm^2$$

short direction use <u>2 legs</u> close hoop $\phi 10$

$$= 2(0.79) = 1.6\,cm^2$$

Repeat the last procedure for Shear wall


2Ø16@15cm
90cm
270cm
90cm
20cm
20cm
450cm
16Ø16
Ø10@15cm
Ø12@25cm